Qualification of Additively Manufactured Materials for Robotic Spaceflight

Bryan W. McEnerney, R. Peter Dillon, J.P. Borgonia,
Andrew A. Shapiro-Scharlotta

Jet Propulsion Laboratory
California Institute of Technology

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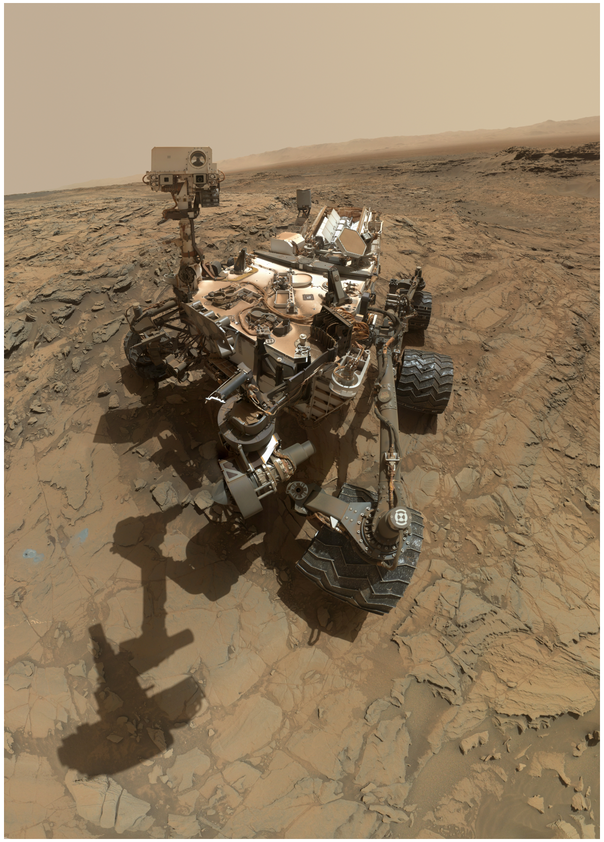
Agenda

1. Overview of Additive Manufacturing at jPL
2. NASA & JPL Qualification Methodology
3. Specific Material Qualification
   - Ti-6Al-4V
   - AlSi10Mg
4. Conclusions
5. Acknowledgements

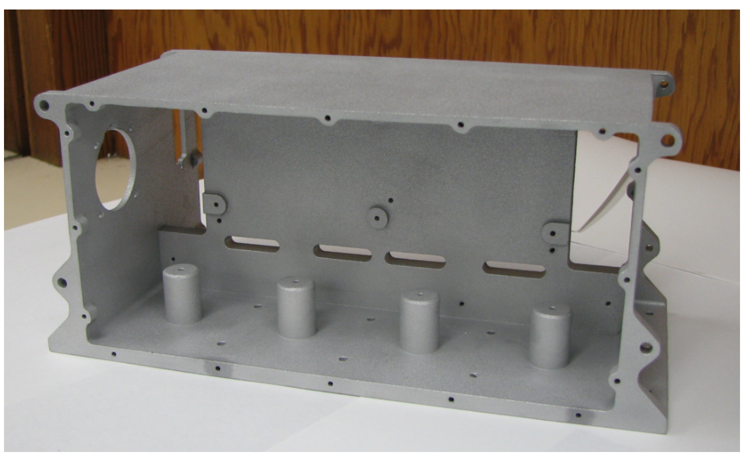


Mars Science Laboratory (Curiosity) / Mars 2020 (Image JPL/NASA)

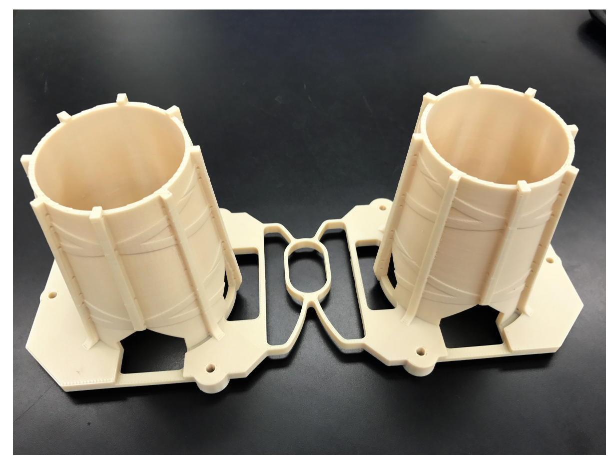
Additive Manufacturing Technologies Overview

Additive Manufacturing at JPL, briefing

- Additive Mfg Technologies
  - Powder Bed Technologies
    - Direct Metal Laser Sintering
    - Electron Beam Melting
  - Powder Deposition Technologies
    - Laser Powder Deposition
    - Cold Spray
  - Wire Deposition Technologies
    - Electron Beam Wire Deposition
    - Gas Metal Arc Welding
    - Laser Wire Deposition
    - Cold Metal Transfer
  - Other
  - Rapid Sand Castings



Direct Metal Laser Sintering (DMLS)
SEP Electronics Chassis (AlSi10Mg)



Fused Deposition Melting (FDM)
Sentinel-6 Antenna Fixture (Ultem 9085)

Additive Manufacturing Materials

Aluminum and titanium alloys comprise 85% of flight structural components

- Ti-6Al-4V produced via EBM (Arcam) process is baseline for flight use due to robust database
- Current AM aluminum offerings (AlSi10Mg, Scalmalloy) don't correspond to existing aerospace alloy classes

Polymerics

- Focused effort on in-house printing of relevant materials systems for thermal standoffs, dielectrics and test equipment
- B-basis analysis used, with Stat17, for Ultem 9085, PEEK, Ultem 1010 and Torlon
- Only for <u>non-structural</u> applications

Gradient alloy systems

- Research effort into tailored properties and behaviors
- Will only be used for niche, low volume applications
- Design specific qualification practices only

NASA Qualification Approach

MSFC-STD-3716

NASA-STD-603X
AM
Standard for
Crewed

NASA-STD-603X
AM
Standard for
Non-Crewed

NASA-STD-603X
AM
Standard for
Aero

MSFC-SPEC-3717


MEASUREMENT SYSTEM IDENTIFICATION METRIC/SI (ENGLISH) UNITS

National Aeronautics and
Space Administration

MSFC-SPEC-3717
BASELINE
EFFECTIVE DATE: October 18, 2017

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

EM20

MSFC TECHNICAL STANDARD

SPECIFICATION FOR CONTROL AND QUALIFICATION OF LASER POWDER BED FUSION METALLURGICAL PROCESSES

Approved for Public Release; Distribution is Unlimited

CHECK THE MASTER LIST — VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

NASA-SPEC-603X

AM Specification
for Equipment
and Facilities

Qualification Approach (cont.)

NASA Non-crewed

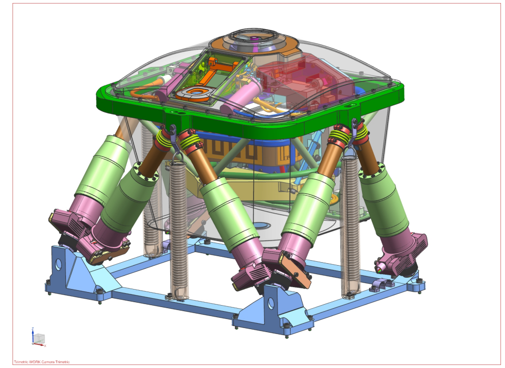
- Covers all non-crewed spacecraft, including launch vehicles and associated hardware
- Will cover parts according to three categories, with sub-categories for risk:
  - Fracture Critical, Structural, Non-Structural
- NASA documents expected for release in September 2020

JPL Approach

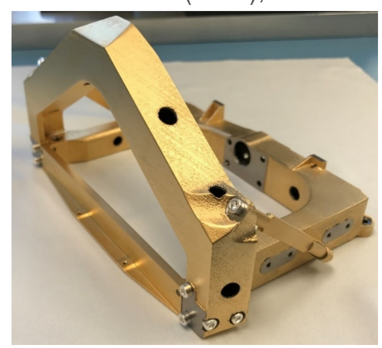
- Temporary approach that will be consistent with the NASA documents
- Focusing on solutions for three primary systems currently:
  - Laser Powder Bed Fusion, AlSi10Mg
  - Electron Beam Powder Bed Fusion, Ti-6Al-4V
  - Fused Deposition Melting, Various polymers
- Approach for each detailed in the following slides

Electron Beam Powder Bed Fusion, Ti-6Al-4V

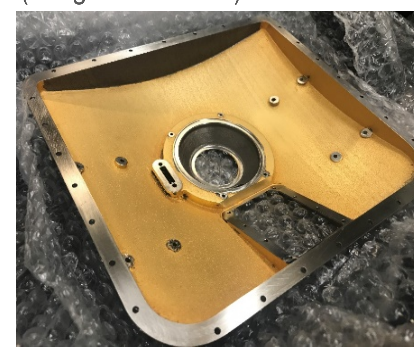
- Leveraging America Makes Activity
  - B-Basis allowables (static) developed with a partnership between CalRAM (Camarillo, CA) and Northrop Grumman (El Segundo, CA)
  - JPL & NASA are conducting dynamic testing
    - 140 axial fatigue and fracture toughness coupons
    - Properties from -150 °C to 150 °C
  - Facility audits and internal specifications to govern all parts
- Additional testing
  - Build-specific tests required for properties that are deemed design critical (e.g. thermal expansion)
  - Acceptable only for unmanned missions
    - Data required to support manned (e.g. International Space Station) missions
  - Proof testing required on all parts
  - Factors of safety being debated
    - Mechanical pushing for 1.4x yield strength, 1.7x ultimate tensile strength



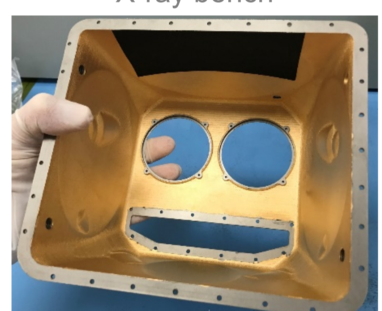
Planetary Instrument for X-ray Lithochemistry (PIXL), Mars 2020 (Image JPL/NASA)



X-ray bench



Front cover

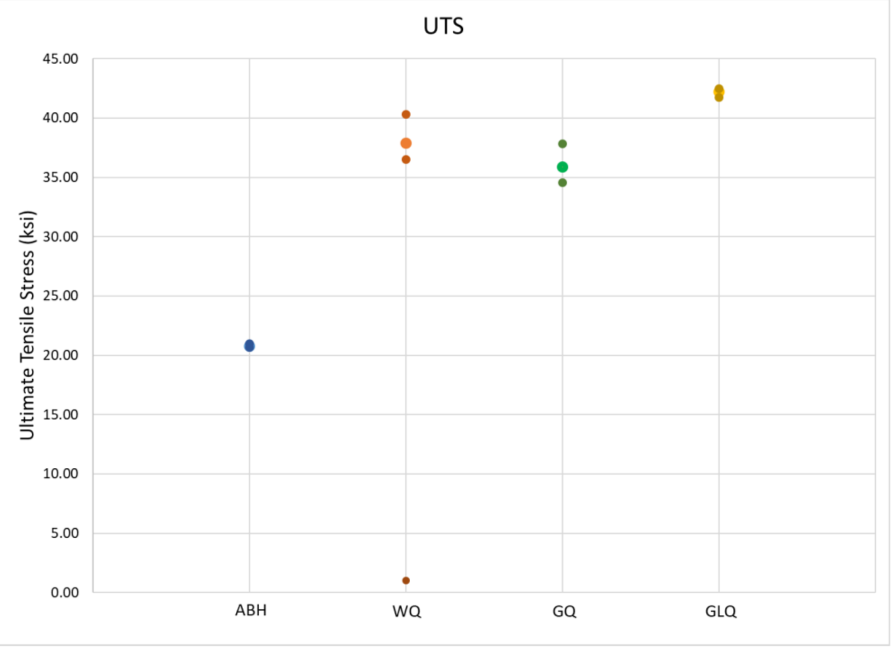


Back cover

Mounting frame

Qualification Methodology (AlSi10Mg)

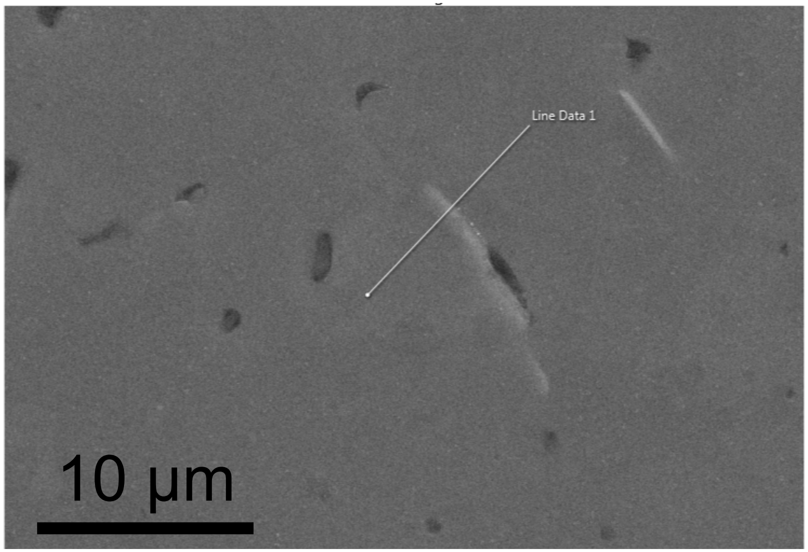
- Identification of insertion opportunities
  - Baseline properties determined through focused testing over a variety of temperatures (critical to JPL applications)
  - Capability determination of thermophysical properties
  - Understanding limited design space for non-traditional alloy
  - All flight parts until 2020 to be built at JPL (EOS M290)
- Additional required efforts
  - Quantification of powder and build variability
  - Heat treatment and qualification of external vendors
    - JPL-published process of solutionizing for 6 hours at 538 °C, rapid quenching to 25 °C and aging at 158 °C for 12 – 18 hours
  - Proof testing

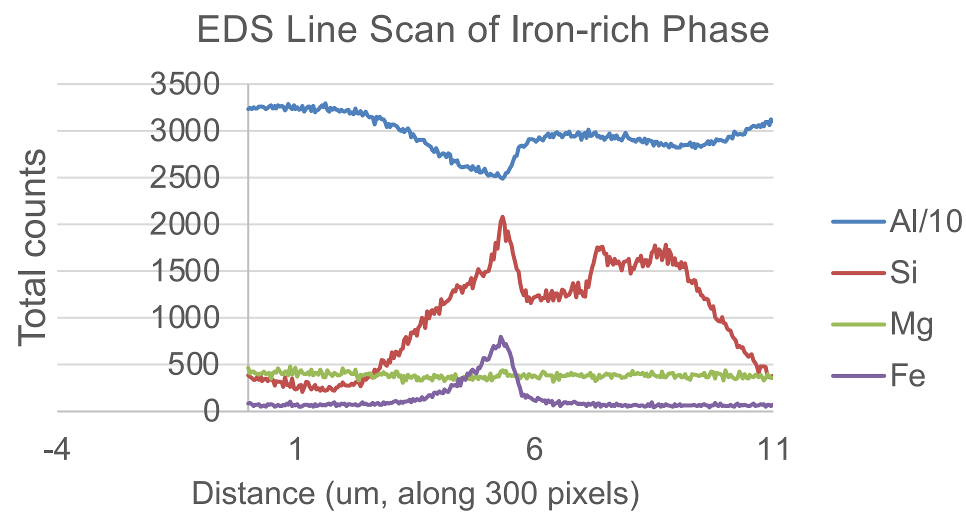


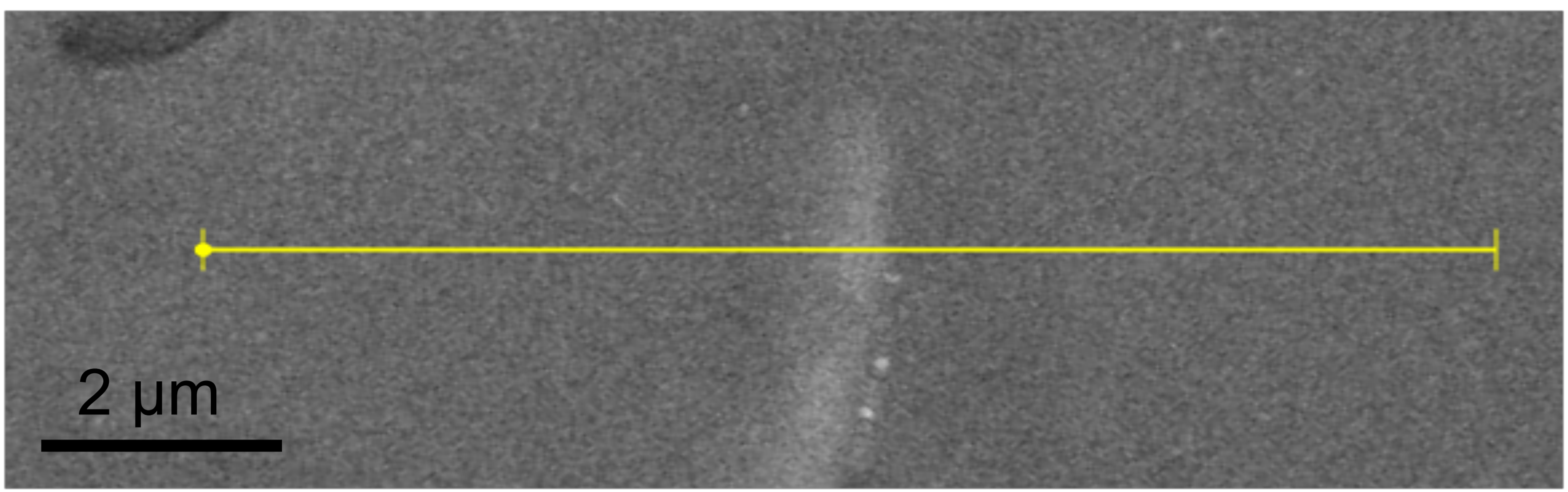
Effects of various quenchants on mechanical behavior
Large dot represents mean of 20 samples, as well as high and low values

ABH – as-built and HIP'ped
WQ – water quenched
GQ – gas quenched (He)
GLW – glycol quenched

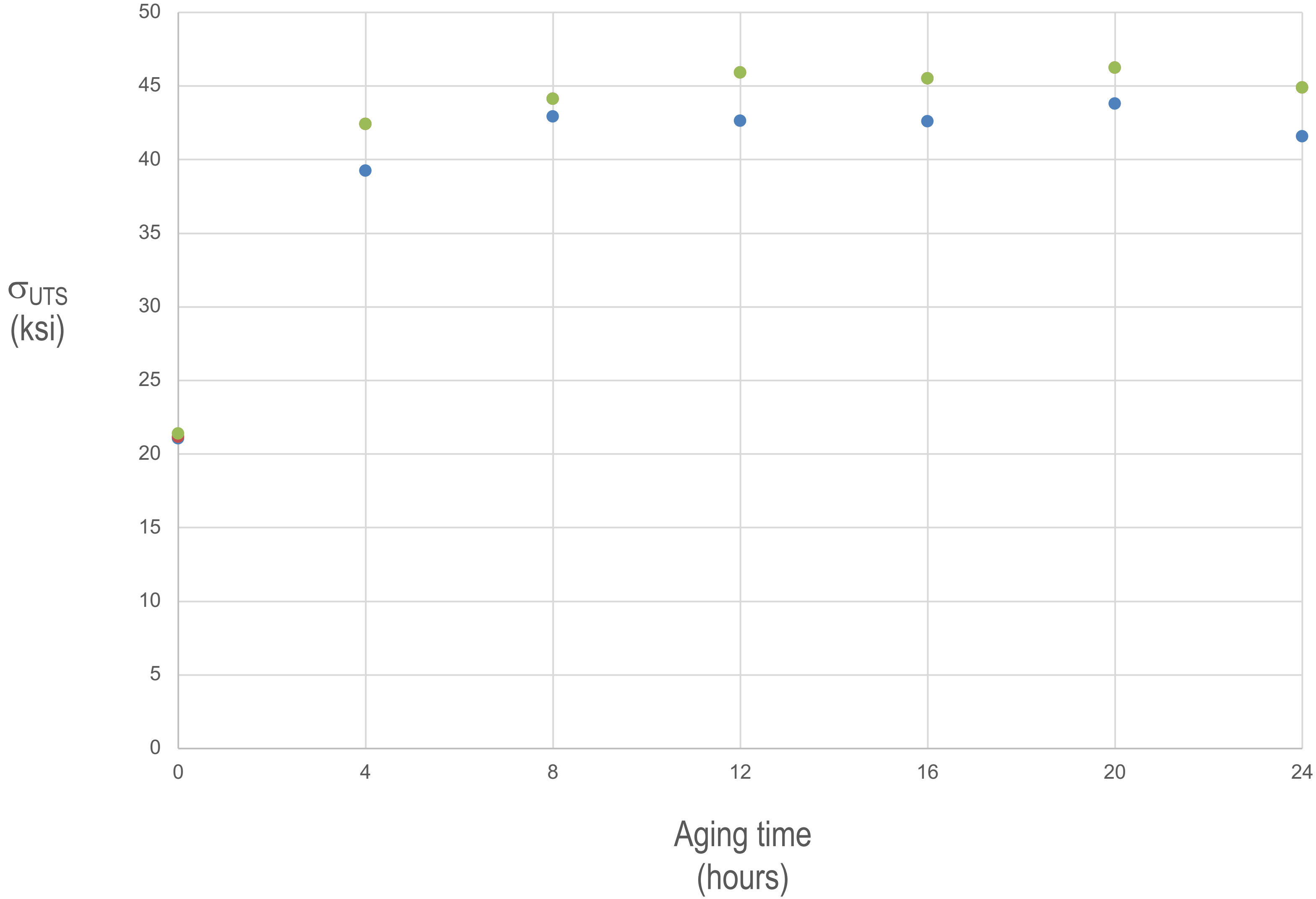
Heat treatment microstructure







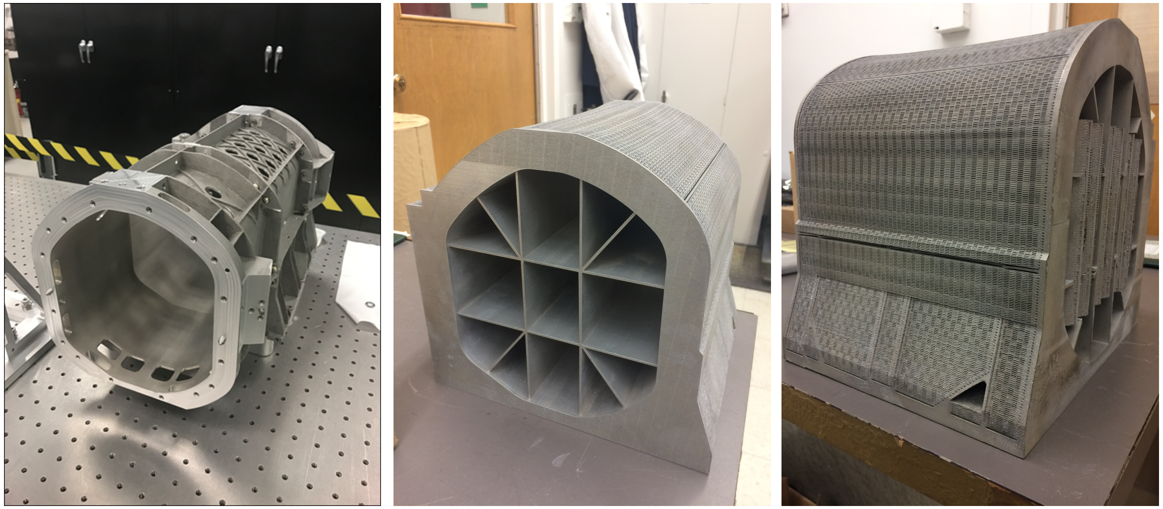
Aging Behavior



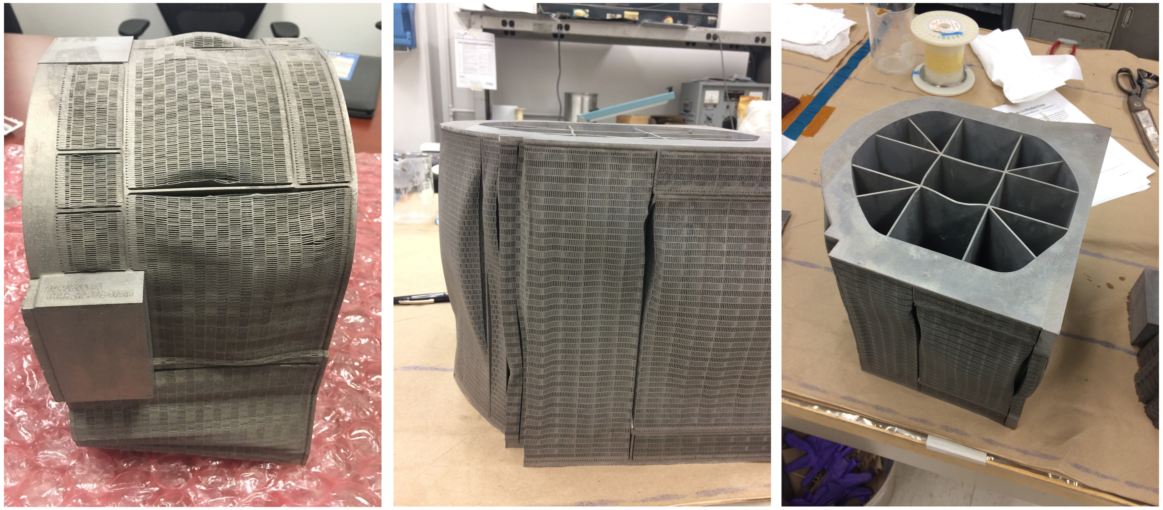
Instron 1331 #395182
Strain-controlled, 0.005 in/in/min
ASTM E8

Insertion Opportunities

- Coring Drill Chassis (Mars 2020)
  - Development unit only (not for flight)
  - Flight hardware will be machined from single billet
  - Built as 3 pieces, machined and bolted together
- Justification
  - Significant schedule and cost reduction from conventional processes
  - Provided significant increase in testing time, due to reduced production schedule
- Challenges
  - Significant size and residual stresses from quenching
  - Proof testing for entire structure



Development Coring Drill, Mars 2020 (Image JPL/NASA)



Conclusions

1. Leveraging NASA and Government resources for applicable systems
2. JPL developing internal processes to cover 24 month gap
    1. Leveraging NASA and internal control methodologies
    2. Aggressive proof-testing and mechanical evaluation at critical design points
3. Non-destructive evaluation
    1. Monitoring progress technically to determine eventual solutions
4. Materials & Processes focused on informed decisions for AM insertion onto flight programs.
    1. Avoiding improper usage (e.g. flat plate)
    2. Understanding complete process flow for post-build challenges (e.g. joining, surface finish, etc.)
    3. Understand nature of desired component

Acknowledgements

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